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AN INTRODUCTION TO THE CONCEPT OF PROFILES

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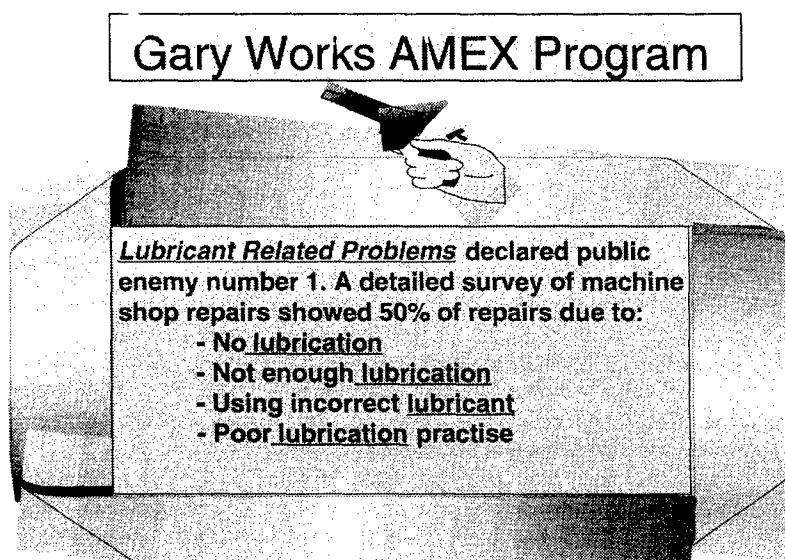
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Abstract

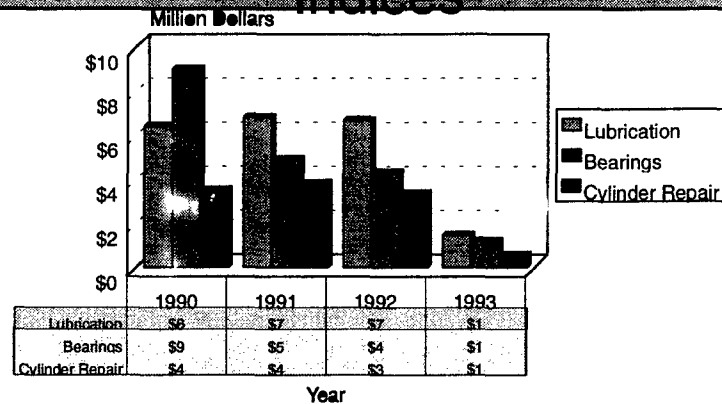
There has been limited general acceptance of lubricant analysis as a predictive maintenance tool in industry as compared to say vibration monitoring. There is perhaps a perception within industry that Lubricant analysis has failed to deliver on some of the promises that it has made. However when one looks at so called benchmark programs that exhibit the practises of industry leaders, and measures the achievements of such programs there is no doubt that if applied correctly that lubricant analysis is an invaluable tool in the development of an advanced approach to maintenance. There are many issues which create a successful lubricant analysis program, one of which is the appropriate use of existing technologies to ensure optimum value in the implementation of a program. This paper introduces the concept of Profiles as a framework for the effective utilisation of the correct lubricant analysis technologies.

Examples of Benchmark Lubricant Analysis Programs

In a large integrated steel mill it was estimated that 50 % of machine shop repairs had a lubricant related origin. A comprehensive program was instituted with almost immediate dramatic results.



Gary Works Key Spending Indices



Indices In Millions of Dollars

Source: Amex News Spring 1993

Other examples are an underground mechanised coal mine implemented a comprehensive on site lubricant analysis program to prevent unplanned downtime, and achieved a \$2M return on investment in the first year. This was achieved by a combination of increased machinery availability, decreased work interruptions, and the partial elimination of built in faults during refurbishment. The result was significant measurable increases in coal production.

The question that remains is why is there such a large disparity gap between so called benchmark programs and others?. There are many reasons for this, however one of the most significant is in the utilisation of existing lubricant analysis technologies. This paper will attempt to provide opportunities for ensuring that the appropriate technologies are used within a meaningful conceptual framework which is referred to as a Lubricant Profile or Profile.

Historical Review Of Lubricant Analysis

Since lubricant related condition monitoring was first implemented just after the second world war it has grown through three distinct generations of development. Each has played a significant role in combining to provide a scientific insight into the workings of lubricated equipment.

First Generation Oil Analysis

Just after the second world war the US army began experimenting with traditional analytical methods for elemental analysis of oil in diesel engines. It was found that certain trends were observed relating to both the wear of the mechanical components together with information on the depletion of additives within the oil. This has led to the broadly applied and familiar field of spectrometric or SOAP (Spectrometric Oil Analytical Procedure) analysis.

SOAP analysis is fairly generally applied around the world and has been successful in the monitoring of internal combustion engines. It has been used with a lesser degree of success in the monitoring of industrial plant such as gearboxes, pumps etc.

A typical SOAP analysis profile would consist of the following components.

Spectrometric elemental analysis for:

- Wear Metals
- Additive Depletion
- Solids and Fluid Contamination

Additional tests were performed for Viscometry, TBN (total base number) or TAN (total acid number), water content, pentane insolubles, dispersancy, fuel dilution etc.

Traditional SOAP analysis suffered from two significant sets of criticisms.

1. The first was that due to the limitation of only seeing particles less than 8 microns in diameter, it was extremely limited in its use in industrial applications which frequently in a healthy state produced particles with an average size of 30 microns.
2. Secondly a typical profile of SOAP analysis results may consist of in excess of 30 different parameters. Generation of huge amounts of data was confusing to the end user who was looking for simple answers.

Second Generation Oil Analysis

In the 1970's and 1980's there were a number of significant developments in instrumentation and analytical techniques for analysis of used oil. Amongst the most important of these were:

Ferrography (Wear Debris Analysis) :

Ferrographic or wear debris analysis consists of the physical analysis of wear debris particles, as apposed to the chemical based technique of SOAP analysis. The premise that this technique made was that differing wear mechanisms produced wear debris of differing physical appearance. By skilfully measuring the amount and physical morphology of the debris an accurate indication of the health of systems was obtained. The criticism of this technique was that the analysis of the actual debris was very skills dependent and subjective.

Particle Counting;

Particle Counting for many years was inaccessible for the routine analysis of used oil due to the cost of instrumentation and the sensitivity of the measuring technique. However in the last few years cheaper more user friendly particle counters have found their way onto the market. Particle counting has filled a hole in the oil analysis spectrum where in clean oil systems such as turbines, compressors and hydraulics the particle concentrations were so dilute that the other recognised methods were of limited value.

FTIR (Fourier Transform Infra Red) Spectrometry

FTIR Spectrometry has recently come of its own as a new applied technology in the field of oil analysis. This analytical technique has been developed around the use of the instrument in combination with computerised procedures for large volume data manipulation and storage. FTIR spectrometry allows accurate determination of the in service degradation of the lubricant. The technique is also able to give a measure of water content and diesel dilution together with a measure of soot in engines.

Other techniques and technologies which have come onto the market and are being utilised in specific applications are gas chromatography and various on line analysis methods.

Technology	Capabilities	Comments
Spectro Metals Analysis	Wear Metals Metallo-Organic Additives Contaminants	Severe Particle Size limitations
FTIR Spectrometry	Lubricant Degradation Fluid Contamination (water) Good for QA & QC of lubricants	Becoming increasingly used as the technology of choice, As FTIR systems and associated data management systems improve.
Wear Debris Analysis	Diagnostic tool for wear related system deterioration. No particle size limitation. Excellent tool for root cause analysis	Limited proactive capability, mainly a diagnostic tool
Particle Counting	Measures solid contamination. Lead technology for monitoring clean oil systems. Laboratory based particle counting relies on accurate laser based detectors.	Measurement technologies, useful for setting target cleanliness levels. Also for specification of filtration, and quality control of unused lubricants.
Viscometry	Good indicator of fluid integrity. Can measure lubricant degradation or misapplication.	

Third Generation Oil Analysis

In this paper we would like to present the concept of third generation oil analysis. As the concept of predictive/proactive maintenance becomes more accepted as a maintenance philosophy so too becomes the need for more accurate specific understanding of problems within mechanical systems. This means that no single analytical technique is better or more appropriate than another for solving a problem. However in combination the various technologies provide a powerful set of capabilities of deriving a holistic picture of machine health. There are two cornerstones to making third generation oil analysis work. These are firstly to select the appropriate **Profile** of tests in the required application and secondly to have a flexible sophisticated information processing system that turns the raw data into clearly understood maintenance information.

Within the development of third generation technologies we introduce the concept of **Profiles** (Lubricant Profiles)

Profiles

A survey of the lubricant analysis marketplace shows that the cost of analysis of a sample in the USA can vary from anywhere between \$5- \$85. Asked for pricing a typical vendor would offer \$10 analysis, \$15 analysis, \$25 analysis or \$40 analysis. The presumption that \$25 analysis is an expanded \$10 analysis may easily be made, however the basis of this premise is in many cases incorrect. For example the \$25 analysis may be limited to analytical Ferrography where the \$10 may be simple spectrometry. The real question which needs to be asked is what exactly should I be doing to cost effectively monitor my machines - and that is where the concept of Profiles is of assistance. The definition of a profile is:

A combination of tests which appropriately monitors the manifestation of failure for that system.
(In other words lets get away from treating everything as a variant of a diesel engine)

Typically in industrial plants there are a large variety of complex systems operating. The application of the profile concept will allow the user to move beyond a simple fault detection approach in order to provide a more comprehensive understanding of the dynamics within such systems. The use of profiles exploits the full capabilities of modern lube analysis technology. In practise this means understanding the operational dynamics within a system together with the failure modes and matching these to applicable tests which will detect and diagnose these conditions. Below I illustrate the selection of two typical profiles, one for a gearbox, and another for a hydraulic system.

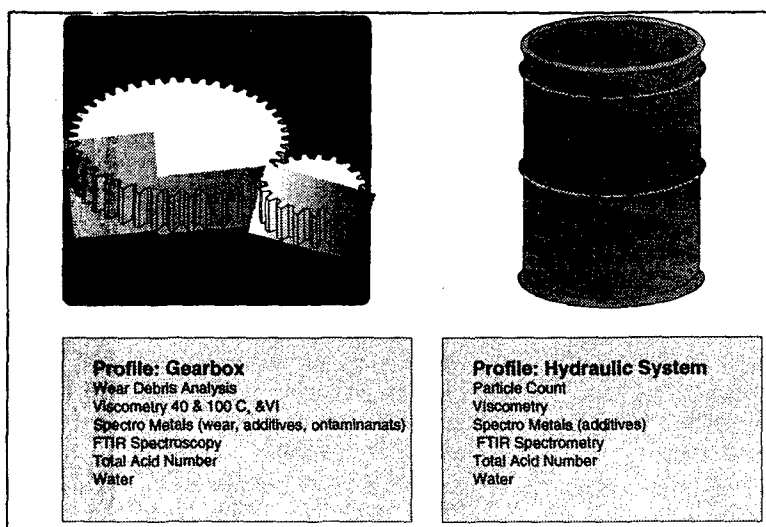


Table 1 Illustration of the use of Profiles for two differing industrial applications

Gearbox	Hydraulic System
Need to monitor: <ul style="list-style-type: none"> • Mechanical wear, which is normally seen in particles larger than the range of detection for spectrometers. Anti wear, anti oxidant and anti scuff additive depletion • Oil oxidation • Acid build up. • Water and other contaminants 	Need to monitor <ul style="list-style-type: none"> • Solid contaminants by particle count • Water • Depletion of anti wear additive • Oil oxidation • Acid build up • Wear

Table 2 Monitoring Objectives for a gearbox profile compared to a hydraulic system

For example a gearbox in a large mechanical drive will require a differing set of tests (referred to as the Profile) to that of a turbine in a nuclear power station. It is therefore important for the condition monitoring practitioner to understand the differing damage and deterioration

mechanisms that occur within a particular system so as to allocate the correct profile in order to optimally benefit from a condition monitoring program.

PROFILE	TESTS	COMMENTS
Turbo Generator	Viscosity (40 C, 100 C and VI) Particle Count Elemental Spectrometry (additive depletion) Karl Fisher water FTIR Molecular Spectroscopy TAN	This profile would have a proactive bias. If wear is detected, inevitably there will have been an associated reduction in residual life of the system. We are monitoring to ensure elimination or at least very early detection of any incipient problem.
Gearbox	Wear Debris Analysis Elemental Spectrometry Viscometry (40, 100 and VI) FTIR Molecular Spectroscopy	Wear is a normal product of operation of most gearboxes. However the nature, extent and mechanism of this wear are vitally important to detect. Influence of lube functionality also monitored.
Standby Diesel Generator Engine	Viscosity (40 C, 100 C and VI) Particle Count Elemental Spectrometry (additive depletion) Karl Fisher water FTIR Molecular Spectroscopy TBN	The condition monitoring approach for such an application has to be very proactive ensuring that no conditions arise that would allow the initiation for a failure cycle.
Grease Lubricated Bearing	Wear particle extraction, followed by wear debris analysis and elemental spectrometry. FTIR Spectrometry	Predominantly a predictive profile which relies on wear debris analysis to define mechanism and extent of damage. FTIR spectrometry detect additive depletion or oxidation.
Hydraulic System with servo valves	Particle Count Elemental Spectrometry (additive depletion) Viscosity (40 C, 100 C And VI) FTIR Molecular Spectroscopy TAN	Predominantly a proactive profile dealing with the principal root cause of deterioration which is solid contamination.

Table 3 A set of typical machinery profiles

CASE STUDIES ILLUSTRATING THE USE OF PROFILES.

CASE STUDY 1 Turbine Lubricant

A turbo generator was sampled in order to review the health of the lubricant. The sample was analysed using a "clean" profile. The results were as follows:

Contaminants:

>2um	843
>5um	342
>15um	57
>25um	14
>50um	2
>100um	0
ISO 2	17
ISO 5	16
ISO 15	13
Silicon	0

Additives:

Magnesium	0
Calcium	0
Barium	0
Phosphorus	9
Zinc	18
Molybdenum	0

Wear Metals:

Iron	42
Chrome0	
Lead	1
Copper	69
Tin	0
Aluminium	1
Nickel	0

Viscosity:

cSt 40C30	
cSt 100C	5
Visc Index	104

Oil Condition:

PPM Water	0
Oxidation	0
Nitration	0

The diagnostic message read:

Excessive wear. In addition, the lubricant is slightly more contaminated than the recommended Target Cleanliness Limit of 17/15/13.

When looked at more closely, using detailed FT-IR spectroscopy, it was discovered that the lubricant was showing severe signs of additive depletion together with indications of base oil oxidation. The detailed conclusion of the analysis was:

Significant indication of lubricant degradation. This situation poses a threat to the reliability of this system. Immediate action is necessary to ensure reliability. Recommend system is drained and relubricated.

The standard FT-IR quantitative methods did not detect additive depletion because the published methods focused on the "wrong" wavelength for this proprietary additive. A well-trained Tribologist knows how often additive packages change and instinctively looks at the entire infrared spectrum instead of trusting a standard computer generated number. This specific new procedure would then be added to the **Profile** for this system.

By understanding the criticality of this system and going beyond "second generation" lubricant analysis, a major dollar loss due to system shutdown was prevented. In addition by modifying the Profile, new real value was added to the analysis set.

CASE STUDY 2 Rolling element bearings

A large rolling element bearing was monitored for 3 months using a "screening" (low cost) profile. The results were as follows:

Wear Metals:	Month 1	Month 2	Month 3
Iron	51	102	36
Chrome	0	0	0
Lead	0	0	0
Copper	2	2	1
Tin	0	0	0
Aluminium	0	0	0
Nickel	0	0	0
Silver	0	0	0
Additives:			
Boron	0	0	0
Sodium	7	10	6
Magnesium	0	1	0
Calcium	4	8	4
Barium	0	2	0
Phosphorus	10	16	0
Zinc	3	5	1
Molybdenum	0	0	0
Titanium	0	0	0
Contaminants:			
Silicon	3	1	0
PPM Water	0	0	0
Oil Condition:			
Viscosity (40C)	64	66	64
Oxidation	0.00	0.02	0.01
Nitration	0.00	0.01	0.01

Month 1 diagnoses read:

Sample has no abnormal indications.

Month 2 diagnoses read:

Increase in iron, will monitor in next sampling.

Month 3 diagnoses read:

High indications of wear . Wear debris analysis indicated wear in the form of fatigue platelets, and metallic oxide. A wear index of 13 was registered. In addition, there was a significant amount of fibre present suggesting perhaps the failure of the filter. We recommend that the unit is carefully analysed for possible problems (compare with your vibration data). Drain and relubricate unit and resubmit a sample after 100 hours of operation.

In month 3, the profile was changed to a more comprehensive industrial profile (which included wear debris analysis and wear index) after educating the client concerning the importance of proper monitoring of systems. If the profile had not been changed to monitor wear debris, the wear may have gone un-noticed as evidenced in the drop in iron content due to the particle size limitations of spectrometric analysis.

CASE STUDY 3 Electric Motors

An industrial plant interested in establishing a lubricant monitoring program sampled a motor bearing. The first analysis performed followed an "industrial" profile. The objective here was to get an overall health indication of the system. It was assumed the system would be too "dirty" for a clean (particle count) profile because the system had never been monitored before. Once the system was flushed and "cleaned up", a "clean" profile was used as a proactive approach to monitoring the newly replaced motor bearing. Results were as follows:

Wear Metals:		Industrial Profile	Clean Profile
	Iron	6	0
	Chrome	0	0
	Lead	79	0
	Copper	211	0
	Tin	142	0
	Aluminium	0	0
	Nickel	0	0
	Silver	0	0
Additives:			
	Boron	0	0
	Sodium	0	0
	Magnesium	0	0
	Calcium	3	5
	Barium	0	0
	Phosphorus	11	67
	Zinc	109	130
	Molybdenum	0	0
	Titanium	0	0
Contaminants:			
	Silicon	2	0
	PPM Water	0	0
Oil Condition:			
	cSt 40C68		68
	cSt 100C	8	8
	Viscosity index	97	97
	Oxidation	0.03	0.00
	Nitration	0.12	0.00

Wear Debris:		Contamination:	
Wear Index	24	>2um	1355
Ave Size	4	>5um	266
Max Size	1	>15um	32
Density	0	>25um	13
		>50um	4
		>100um	2
		ISO 2	18
		ISO 5	15
		ISO 15	12

By monitoring the system as a "clean" profile one adopts a more proactive approach, thereby eliminating a primary root cause of failure condition. The consequence of this is to exclude abrasive wear as a cause of system failure. This bearing is now maintained at a high level of cleanliness, where the slightest indication of wear, or contamination is detected very early on, and remedial action is immediately taken. It is assumed that this bearing will have infinite life, provided no external factors create a failure condition.

Lessons To Be Learned

As Lubricant technology has matured we have a variety of advanced analytical tools which identify differing failure causes within systems. To ensure optimal value within a lubricant analysis program it is important to :

1. Familiarise ourselves with the capabilities and deficiencies of the various technologies.
2. Recognise that the concept of **Profiles** provides a useful conceptual tool for devising appropriate tests for different systems.
3. For condition monitoring professionals to recognise the characteristics of a system in order to apply appropriate **Profiles** within the context of the analytical program.